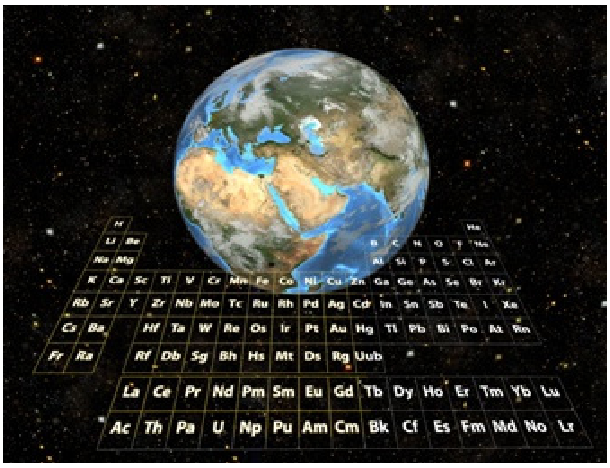
# Rare earth elements and recycling possibilities

**SUMMARY** *Rare earth elements (REEs) are a group of 17 metallic elements mined in ores containing low quantities of REEs. They have particular properties essential to many industries. REEs are key components of clean energy and high-tech growth industries, and are therefore considered a critical raw material.*

*REEs are imported into the European Union (EU) from a very limited number of producers. Until recently, China has been almost the sole supplier of REEs to the rest of the world. Demand for REEs is high and steadily growing, since more and more products include REEs. The REE market is therefore of economic and geopolitical importance.*

*Alternatives to the primary supply of REEs from mined ores are being developed to bring relief to the REE market. Recycling of REEs, from materials used in spent products, provides a secondary supply. However, closing the REE "life-cycle" is a technological challenge, due to the specific uses and properties of the elements. Recycling REEs is still at an early stage.*

*Appropriate conditions for recycling REEs are needed, at every step from collecting useful spent products to supporting research and applying technologies specifically focused on REEs. EU waste legislation and raw materials initiatives are contributing to addressing REE challenges.*



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In this briefing:



## Uses and availability of REEs

**Rare earth elements**

Rare earth elements (REEs), also referred to as "rare earths" or "rare earth materials", cover 17 chemical elements, including scandium, yttrium and the 15 lanthanides[1].

**Categories of metals**

Metals are grouped into **ferrous** metals, **non-ferrous** metals, **precious** metals and **specialty** metals. REES are included in the specialty metals, which are used in small quantities for their physical and chemical properties.

*Extracting REEs from the earth's crust*

REEs are not rarer than silver or lead, but they occur in nature within minerals, in limited concentrations, and not as metallic elements.

REEs can be found in various types of deposits, but are only extracted from a few minerals[2]. REEs are hardly ever mined as the only or primary product and some of them are extracted as by-products of iron, titanium, uranium, zirconium or tin mining. In addition, some ores include radioactive elements.

Processing the different ores requires specific mining, separation and extracting technologies. It is also difficult to separate different REEs from each other since they are chemically close.

**Author**: Cécile Remeur
**Contact**: cecile.remeur@ep.europa.eu

In addition, the REE supply chain (extracting, refining and alloying) involves chemical treatments which are energy-consuming and have significant impact on mining sites and the environment[3].

*REE products*

REEs are used in the form of compounds, in particular oxides, chlorides or carbonates. All three are referred to as rare earth oxides (REOs).

REOs' value depends on their **purity**.

*REE reserves*

The EU has few reserves which could be mined economically. These are located in Sweden and Germany; with further possible sources in Ireland.

China owns a large part of the world's known reserves (38%). The Commonwealth of Independent States (CIS), USA, Australia and India also have reserves and mines. Other promising areas are in Greenland, South Africa and Japan.

Most reserves have two dominant elements (Lanthanum and Cerium), and not all REEs are equally present in ore reserves. Bringing a new mine on-stream is a complex and long-term project (10 to 15 years) according to experts.

**Examples of industrial REE uses**

- In **magnets** in electrical and electronic components, wind turbines, hybrid and electrical vehicles and in medical devices (e.g. magnetic resonance imaging, MRI);
- In some **phosphors**, used in e.g. screens, energy efficient lighting and laser devices;
- In **glass** for absorbing ultraviolet radiation, colourising and decolourising, polishing or altering refracting index (e.g. camera lenses);
- In protective **coating** used in e.g. catalysts;
- In **alloys** in e.g. metals used in rechargeable batteries;
- In **ceramics** to improve strength and toughness (e.g. semiconductors, microwave dielectrics);
- In nuclear **energy** and **defence** applications;
- **Research** on speed and satellite communications, magnetic refrigeration, energy storage (fuel cells) and water treatment (filtering).

## Industrial uses

*Properties of REEs*

REEs have been used since the 1950s for their magnetic, electrical, luminescent, optical and chemical properties.

REEs made possible the miniaturisation of IT components and batteries, which is of particular importance in the green energy[4] (e.g. in wind turbines and photovoltaic cells) and high-tech industries.

*Categories of industrial applications*

REEs are used in a wide range of industries, in different forms and quantities. A non-exhaustive list of industrial applications is included in the box.

## REE market

**A dominant producer**

The REE market is characterised by enormous country concentration on the supply side. China's share of production has recently been above 90%. In addition, it has also mastered processing, refining and metals alloying technologies (downstream capacity).

China gained this monopolistic position in the 1990s, thanks to its geological reserves of good quality, and the wide range of its REE products. Since 2010, China has tightened its production and export limits. This triggered ongoing trade disputes and brought the geopolitical aspects of the REE market to the forefront. China's restrictions consequently acted as an impetus for developing strategies to diversify REE supply sources. New providers are entering the market (US, South Africa, Brazil and CIS), while long-term projects to rebalance the trade have been launched.

**Increasing demand**

REEs, used in varying quantities, are essential to many industrial products.

**Author**: Cécile Remeur
**Contact**: cecile.remeur@ep.europa.eu

Demand is less concentrated than supply. However, China also takes the biggest share (67% in 2011). This is not expected to diminish, with Chinese industry's extensive use of REEs. The EU imports all of its REEs.

Global demand is expected to grow rapidly, (experts estimate growth rates of between 8 and 15% per year). This will be driven by the growth of REE-consuming industries.

**Where do metals entering the recycling loop come from?**

**Pre-consumer scraps** are residues generated during fabrication or manufacturing, rather than from spent products. Some can easily be re-used (e.g. from magnet production).

Old or **post-consumer scraps** come from consumer or industrial products. They are likely to be complex scrap in which metals are combined, melted or even altered.

### Supply-demand balance

In the short term, the market is characterised by the fact that increases and volatility of REE prices are not directly reflected in a good's final price[5]. Price changes have not led in the short term to any adjustment between demand and supply.

The supply-demand balance, in the near future, shows important differences among REEs but it is generally characterised by under-supply. Tensions are particularly likely for five REEs (Neodymium, Europium, Terbium, Dysprosium and Yttrium) for which demand is expected to grow by up to 30%[6]. Only for Lanthanum is a surplus expected.

New supply sources will take time to reach world markets. In the longer term, alternative sources could bring relief in the REE market.

As a result of the supply restrictions, REEs have been placed on most countries' critical or risk list and labelled as critical materials.

### Alternative sources

Alternative supply sources aim at mitigating scarcity and alleviating supply tensions.

The objective is twofold: to smooth the effect of price volatility and to ensure long-term REE availability, providing some stability for industries dependent on REEs.

Urban mining is among the alternative sources. This refers to recycling of spent products (extraction of metal from waste) but is broader since it also encompasses collection from closed landfills.

Options include:

- developing reuse and recycling to generate secondary supplies,
- stockpiling, which does not increase supplies but aims at overcoming supply shocks, and
- research and development on substitute technologies.

**Substitute technologies**

REEs are used for their specific properties which makes them difficult to replace. Substitution may require a change in product design or a modification of the product's properties or yield. In some cases, the substitutes are other REEs or substances which are equally expensive and/or unsustainable.

However some projects could be more promising, for instance research on catalysts without metals.

## Recycling of REEs

In theory metal is perpetually recyclable although losses do occur in practice[7]. In reality, a closed-loop recycling system is not equally achievable for all types of metals. Recycling REEs is particularly challenging.

### Metal life cycle

*Phases*

The life of metal can be described in phases:

- metal used in a product according to an established design. Metal becomes part of the **in-use stock of metals**.
- products having reached their end of life become **waste**; which can be disposed of or collected for recycling.

- when the metal included in a spent product is not collected or improperly recycled, it enters into an **open life-cycle**.
- when the metal is properly collected (pre-processing), it enters into a **closed life-cycle** when effectively recycled (processing).
- metal goes back into the metal loop (stops being waste), as secondary metal supply.

A pre-requisite for recycling is that products are collected and properly processed. In addition, achieving operational and efficient metal life-cycles raises scientific and practical challenges related to the physical limits of closed-loop recycling.

*EU provisions on recycling waste*
Recycling waste relates to the use of spent products. Directive 2008/98/EC on waste management defines, in particular, hazardous waste and recycling targets. REEs are listed amongst the non-hazardous waste.

**Quantity of REEs used in...**

- a 1.5 megawatt wind turbine includes some 350 kg of REEs (mostly neodymium),
- an electrical vehicle contains REEs in the motor, up to some 30kg, in batteries (with 10-15 kg of lanthanum and 1 kg of neodymium), in glass and mirrors, in fuel and catalytic converters and in electronics.
- smartphones include estimated quantities of 50 milligrams of neodymium and 10 milligrams praseodymium (in loudspeakers).

## Recycling metals

*Types of metal recycling*
There are two types of recycling:

- functional recycling, in which metal is returned to raw material production
- non-functional recycling, which results in materials where specific metals are not separated. It is beneficial for the environment but from a metal perspective, it amounts to an open life-cycle, with the specific properties of the metals being lost.

Very few metals are found in pure form in spent products. Separating the metal from other components found in the spent product is needed to reach the level of purity of the recycled metal which will guarantee its quality (i.e. that it has the same specific properties as a virgin metal).

*EU provisions on product recycling*
The following provisions on recycling products at the end of their life cover aspects of metal recycling:

- Directive 2012/19/EU on waste electrical and electronic equipment (WEEE);
- Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and
- Directive 2000/53/EC on end-of-life vehicles.

Although these Directives do not focus on metal recycling, the products covered include metals and in particular REEs.

Some of them include low quantities of REEs per product, but these are products produced in large quantities with a short life-span (for example, in consumer electronics).

When quantitative recycling obligations are set, this may result in recycling the most abundant substances in greater quantities rather than more valuable and scarce metals such as REEs.

## Recycling REEs

*Specific challenges*
Recycling REEs becomes economically interesting when prices of primary supply are high.

According to experts, REEs are normally recycled using routine recycling techniques designed for standard metals, which are rather outdated, instead of specific processing which takes their properties into account.

In addition, products including REEs are not widely collected for processing as urban mines. A significant part of electronic products in particular is sent outside the EU, where they might not be dismantled properly to recover REEs, or be disposed of in an environmentally friendly way.

*Assessment*

REE recycling is still at an early stage. No data are available by product or by Member State. In total, less than 1% of REEs currently enter the recycling loop.

End-of-life recycling rates show how much, in percentage terms, of metals are recycled. This indicator does not distinguish the origin of the recycled scraps (pre and post-consumer[8]). Rates for different metals are included in the April 2013 UNEP report on metal recycling. REEs have amongst the lowest rates of all metals, whatever method is used.

Only half of the REE elements[9] are being, or are currently capable of being, recycled.

Some spent products do not enter REE-recycling because of the limited quantity of REEs they contain, and separation issues (catalysts, glass and alloys). Technology is available for ceramics, some phosphors in lamps, batteries[10] and, in particular, electrical car batteries. Research on recycling magnets could be promising.

Some products containing REEs have a rather long life-span (e.g. wind turbines) and if recycled they will create a secondary supply within decades. In contrast, electronic devices (for example mobile phones) have a much shorter life time, which results in a constant need to produce new replacement products. The corresponding demand for REEs is not met by secondary supply from spent products.

Actions have been launched to promote recycling of REEs within the LIFE programme framework. In addition, some businesses are developing specific technologies to recycle REEs and using them in their industries to recycle certain REEs.

## Addressing challenges in the EU

### Creating conditions for recycling

Short and long-term improvements would contribute to optimising recycling to provide secondary supply REEs. Since recycling consumes less energy and chemicals than mining, it would also bring environmental benefits.

In the **short term**, the collection of spent products containing REEs could be further improved in terms of quantities. Separate deposits for consumer goods would prevent losing this potential resource.

**A longer term** action is to build a recycling economy. This includes, in particular, creating products consuming as few REEs as possible and allowing as much dismantling and recycling as possible, as well as strengthening existing ecodesign provisions.

### Developing technologies for REE recycling

Developing technologies designed to recycle REEs is essential to extract REEs from urban mines.

Some countries, whose industries depend on REEs – such as Japan and the United States, have supported research and development in this field. In the EU, joint or national projects are ongoing, focussing on raw materials.

### EU institutions

At EU level, REE is included in several actions. They are covered by the Commission's raw materials initiative and the communication on an "innovation partnership on raw materials". These address recycling in the medium and long term as valuable waste "urban mines", stressing the value chain (from extraction and processing of raw material, product design and use to end of life) and the potential of better product design in order to ensure their recyclability at the end of life.

**Author**: Cécile Remeur
**Contact**: cecile.remeur@ep.europa.eu

In the **European Parliament**, the 2011 own-initiative report "An effective raw materials strategy for Europe" stresses the importance of recycling valuable elements such as REEs, investing in related recycling and fostering relevant research and development activities.

## Main references


1. Rare earth elements, British Geological Survey, November 2011.

2. Challenges in Metal Recycling, Reck, B.K and Graedel, T.E., Science 337, 8/2012.

3. Study on Rare Earths and Their Recycling ÖKO-Institut, 2011.

4. Scarcity of Rare Earth Elements, a review commissioned by the Royal Netherlands Chemical Society, June 2012.

5. Substitutionability of Critical Raw Materials/ K. Halme e.a.; European Parliament Policy Department A, 2012.

6. Metal Recycling – Opportunities, Limits, Infrastructure, a report of the Working group on the Global Metal Flows to the International Resource Panel/ UNEP, 2013.

7. Recycling rates of metals - a status report, a report of the Working group on the Global Metal Flows to the International Resource Panel/ UNEP, 2011.


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## Endnotes

[1] A table including symbols and atomic numbers can be found in "Lanthanide Resources and Alternatives" by Oakdene Hollins research and consulting, p. 9 of the electronic version.

[2] REEs are mainly extracted from *bastnaesite*, *monazite*, *loparite.*

[3] Producing sulphuric and hydrofluoric acids, as well as radioactive waste in some.

[4] Uses of rare metals in low-carbon energy technologies are assessed by a 2011 JRC study "Use of Critical metals in strategic energy technologies" which focuses on the six technologies of the Strategic energy technology plan (SET-Plan) i.e. nuclear energy, solar energy, wind energy, bioenergy, carbon capture storage (referred to as CCS) and electricity grids

[5] This is partially because many consumer goods have an extremely small REE content (e.g. numerous IT products), so prices are not directly affected by REE price movements.

[6] These REEs are used in magnets and phosphors in particular.

[7] This has to be nuanced as recycling result involves losses (Markov chain modelling, see Challenges in Metal Recycling (p. 692). See also in this context table 38 in 2013 UNEP report (reference above) on losses at different stages.

[8] Possible shortcomings of this general concept are discussed in the above-mentioned article Challenges in Metal Recycling (p. 690).

[9] Publicly available information shows indications of recycling in practice or research stages for the following elements: Yttrium Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Europium, Terbium and Dysprosium, see for instance reference 2 p.127-132 (paper pages 105-110). For Indium see box 12 in UNEP report under reference 4.

[10] See Substitutionability of Critical Raw Materials and UNEP (2013) Metal Recycling – Opportunities, Limits, Infrastructure.

**Author**: Cécile Remeur
**Contact**: cecile.remeur@ep.europa.eu